Extragalactic class I methanol masers: A new probe for starbursts and feedbacks of active galaxies

Xi Chen
Guangzhou University
Shanghai Astronomical Observatory

IAU Symposium 336: unlocking the mysteries of the universe, Cagliari, Italy, 4-8 September 2017

Outline

- Introduction: Methanol Masers
- Our recent research on extragalactic class I methanol masers
  - Extragalactic class I methanol maser surveys with ATCA
    - Detections in two starburst galaixes: NGC253 and Arp220
  - Class I methanol megamaser surveys with GBT
    - Detections in ~10 OH or water megamaser galaxies
  - Follow up higher angular resolution observation with JVLA
  - Other detections with JVLA and ATCA
- Summary

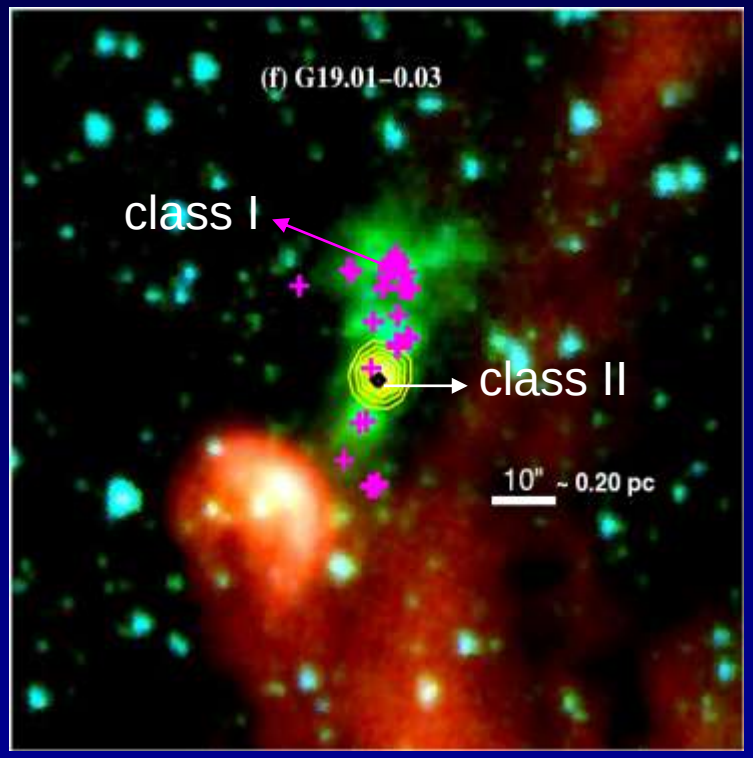
Methanol Masers

- Class I masers are usually associated with outflows, spread over ~10”
  - ✓ Rich transitions:

    9.9, 25.0, 23.4, 25.5, 25.9, 26.8, 27.4, 28.2,28.9, 29.6,30.3, 36.2, 44.1, 84.5, 95.2, 104.3, 132.9, 146.6 GHz

- Class II masers are usually associated with HII regions, mm sources, and OH masers, locate in a compact region within ~1”, possibly associated with disks or jets.
  - ✓ Rich transitions:

    6.7, 12.2, 20.0, 23.1, 29.0, 37.7, 38.3, 38.5, 86.6,86.9, 107.0, 108.8, 156.5, 156.6, 156.8, 157.2 GHz



Known Methanol Maser Survey in the Milky Way

- Class II methanol maser survey:

  – Rich sources at 6.7 GHz (~ 900), good targets for parallax measurement

  - 519 in the catalog of Pestalozzi et al. 2005;
  - 48 found in Arecibo 305-m survey (Pandian et al. 2007);
  - ~350 detected in MMB survey with Parkes (Green et al. 2008); follow-up ATCA observations (Caswell et al. 2010, 2011; Green et al. 2010, 2012; Breen et al. 2015…);

- Class I methanol maser survey:

  mainly at 36, 44 and 95 GHz:

  - Only ~ 200 class I methanol masers were detected in our galaxy before 2010 (Val'tts et al. 2010)
  - A series of survey for 95 GHz class I methanol maser surveys have detected ~ 300 new class I maser sources
    - Spitzer GLIMPSE-EGO sample (Chen et al. 2011, 2013, ApJS)
    - 1.1mm BGPS+GLIMPSE point source sample (Chen et al. 2012, ApJS)
    - Molecular Outflow sample (Gan & Chen et al. 2013, ApJ)
    - 1.1 mm BGPS sample (Yang et al. 2017, ApJS)
  - **A total of ~ 500 sources were found to have class I maser at 95 GHz in our Galaxy.**

Extragalactic masers — Methanol??

- **OH and H_2O masers are very rich in our Galaxy (a few 1000)**
  - ✓ Star forming regions
  - ✓ Envelope of evolved stars



Megamaser emission in extra-galaxies (>100 galaxies)

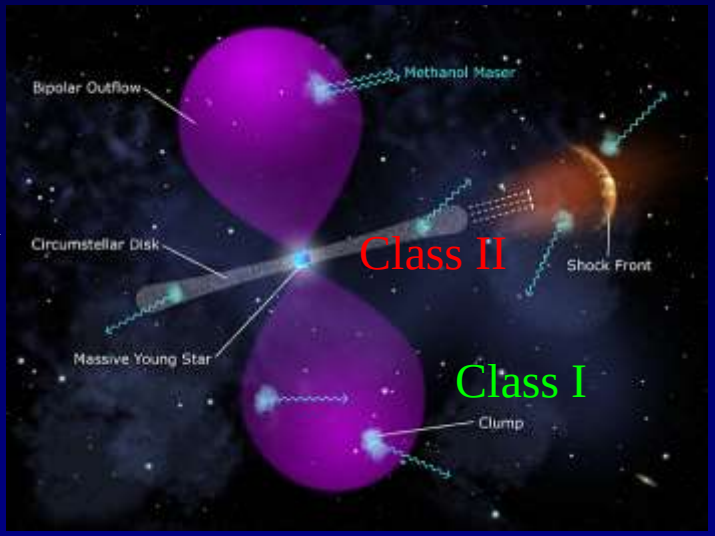
- **Class I and II methanol maser are also very rich and strong in our Galaxy**
  - ✓ ~ more than 1000 in the star forming regions

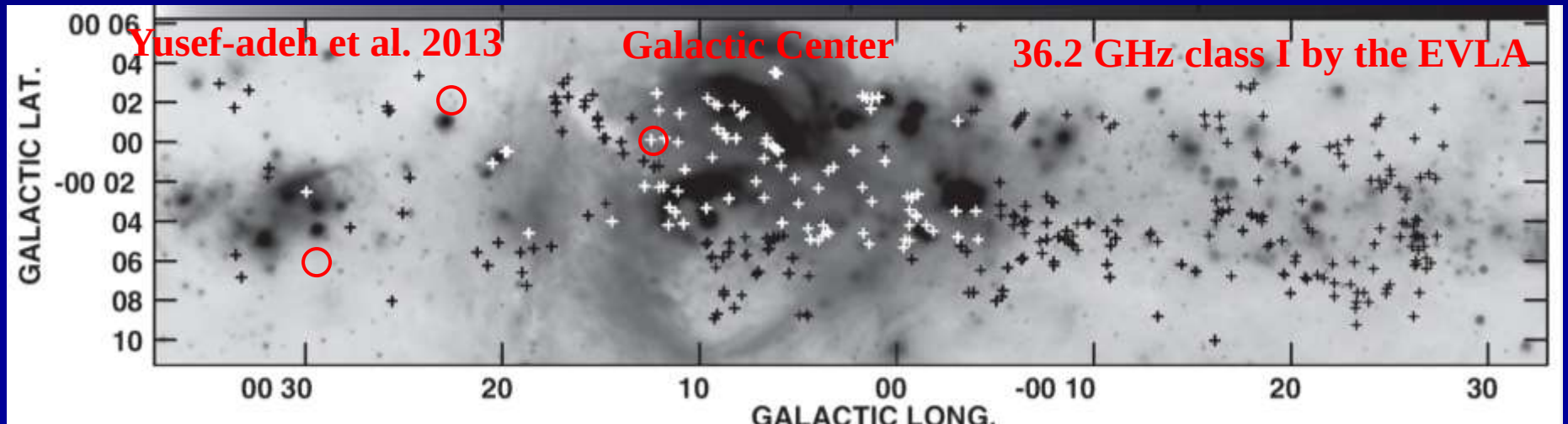


How is about methanol maser emission in extra-galaxies??

Extragalactic methanol maser research

- Extraglacitc class II methanol maser surveys
  - Over one hundred extragalaxies with OH megamaser and Ultra luminous infrared emission were searched, but no detections were made (e.g. Darling et al. 2003).
    - ✓ **Two nearby galaxies (LMC, M31) were detected in the star forming regions.**
  - Class II methanol abundances might be confined to region near protostars in the extragalaxies, and thus not exist on the large paths needed to amplify the magamasers
- Extragalactic class I methanol masers?
  - They might be easily excited in the larger-scale nuclei region of the extragalaxies
- Class I methanol masers in our Galaxy center



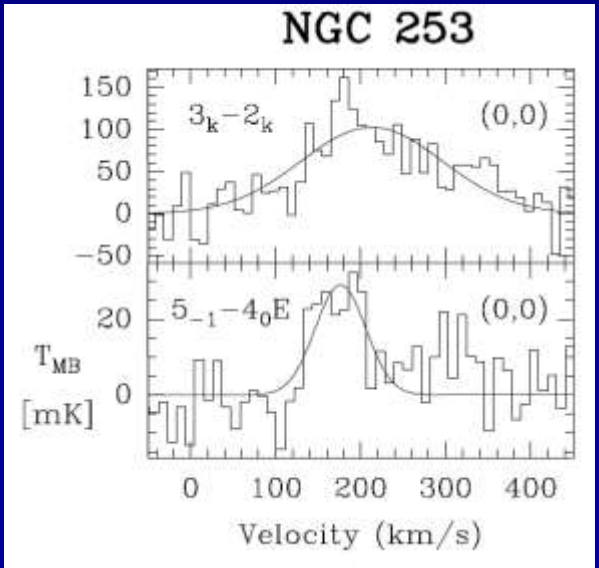


Theory and previous observations

- Theory: class I extragalactic methanol maser emission (Sobolev 1993)

Transition	Frequency (GHz)	Tb (K)
4_{-1}-3_0 E	36.2	32
5_{-1}-4_0 E	84.5	18
6_{-1}-5_0 E	132.9	7.1
7_{-1}-6_0 E	181.3	2.1
7_0-6_0 A^+	44.1	1.3
...		
...		

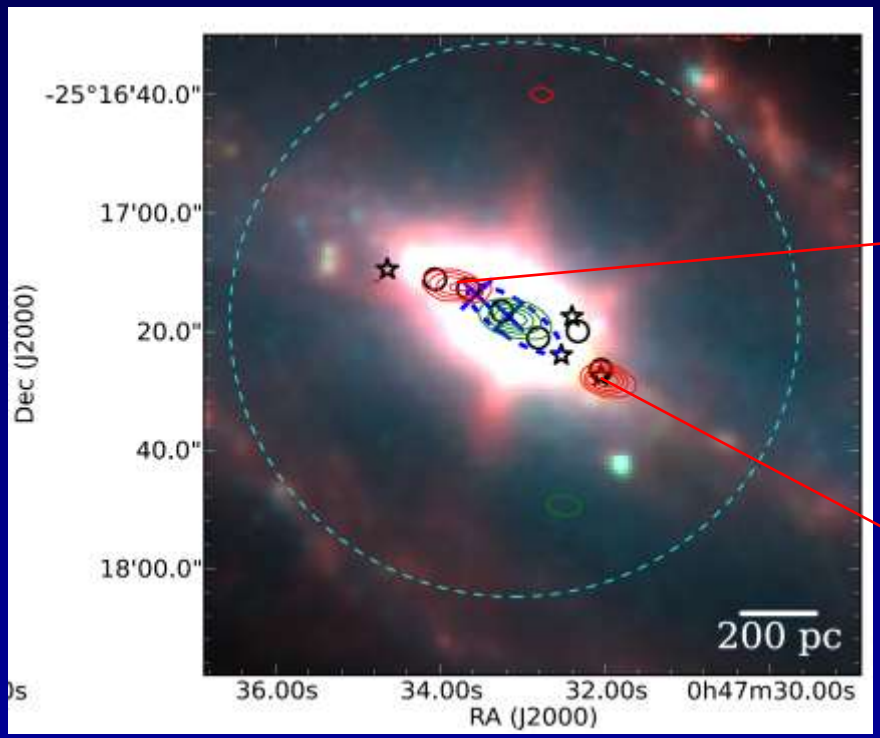
- Observations (Single dish): 84.5 GHz class I (Huttemeister et al. 1997)

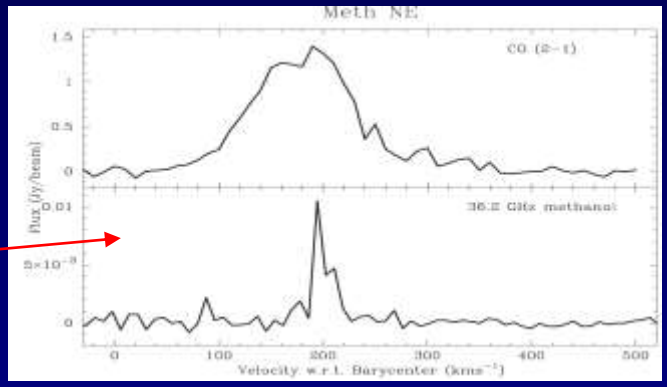


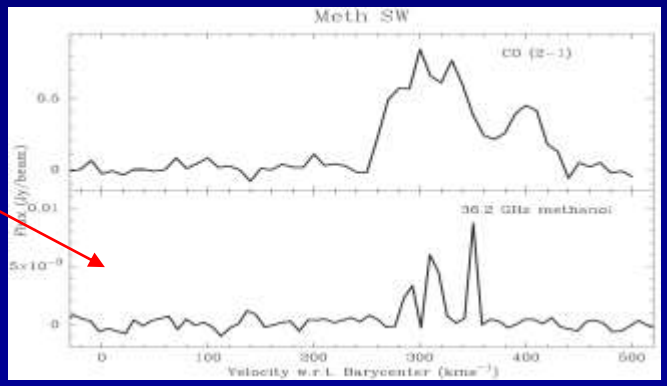
Our recent research:

ATCA survey at 36.2 GHz: ~ 20 OH and H_2O maser galaxies (2014 May)

- 36.2 GHz methanol masers towards NGC253 imaged by ATCA at H168 array:
  Ellingsen S.P., Chen X. et al. (ApJL 790, 28, 2014)



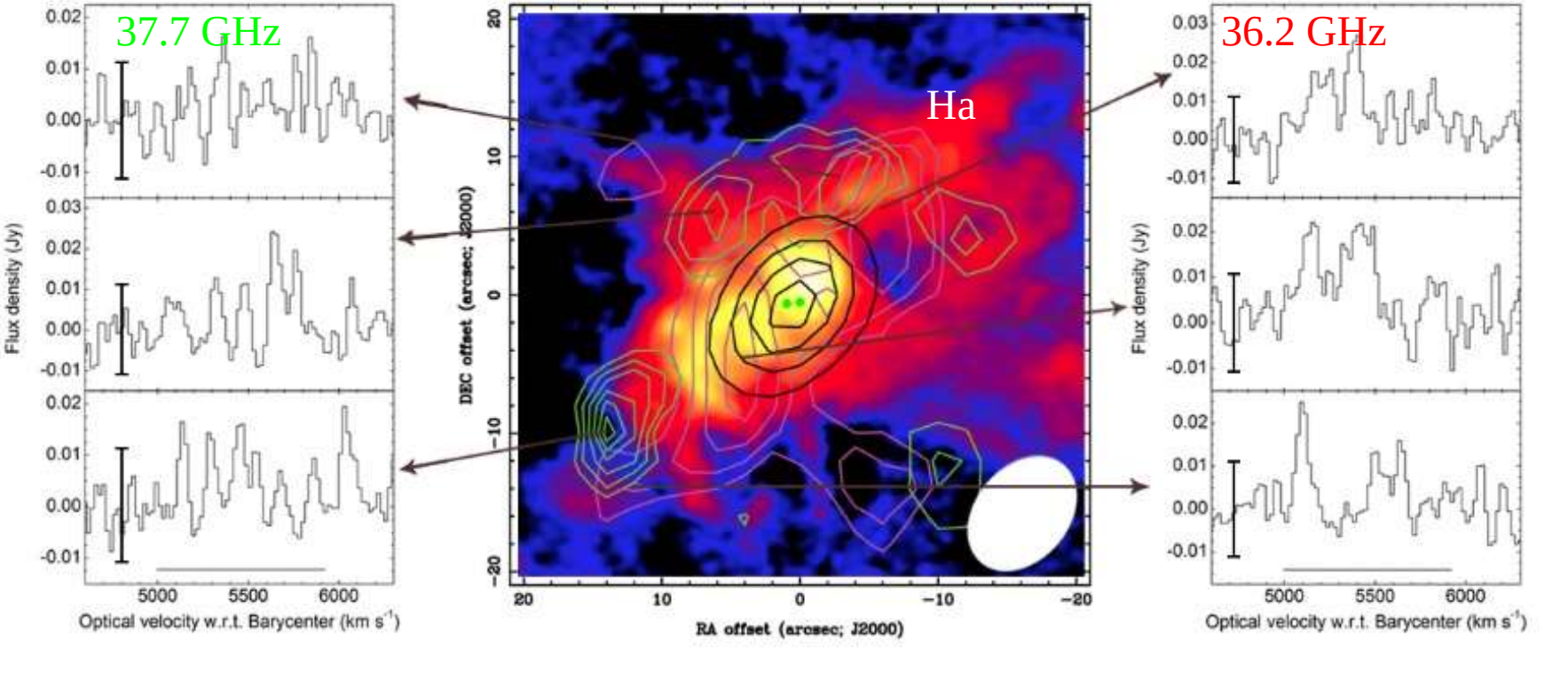




Maser emission characteristics:

1. Narrower line width and stronger (>30 times) emission than those in the thermal conditions
2. Significant offset from the central molecular zone (CMZ) of the galaxy.

- First detection of methanol megamaser
  - Arp 220 imaged by ATCA at H168: Chen X. et al. (2015, ApJL)



Maser emission characteristics:

1. Narrower line width and stronger (>30 times) emission compared to thermal conditions
2. Significant offset from the central molecular zone (CMZ) of the galaxy.
3. Observed towards regions where there is strong Ha emission -> star burst

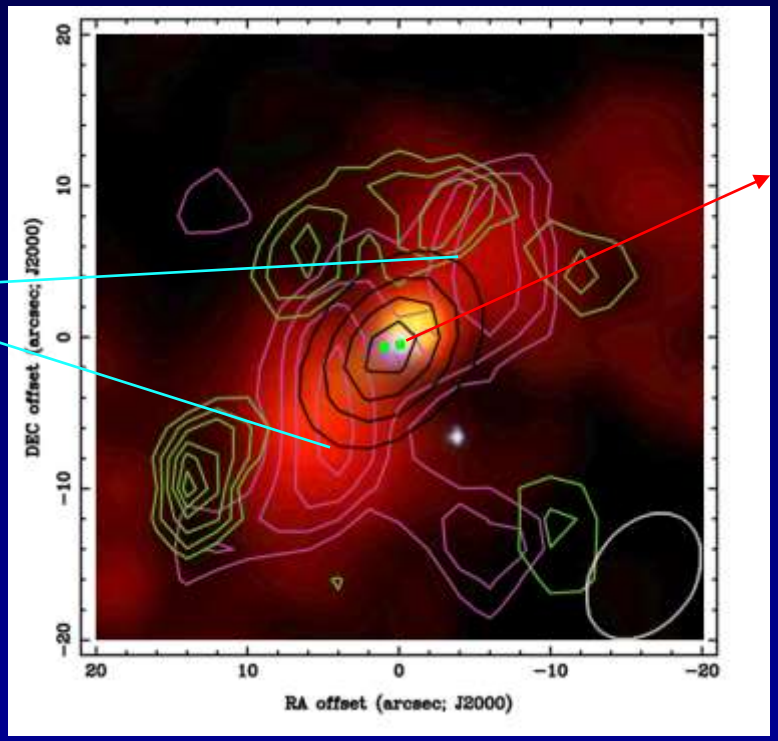
Methanol megamaser: a new probe for the feedback of active galaxies?

Chen X. et al. (2015, ApJL)

Class I methanol in
Soft X-ray plume
outflow region

↓

Large-scale feedback



OH and H_2CO maser in nuclei

↓

Inner feedback of AGN

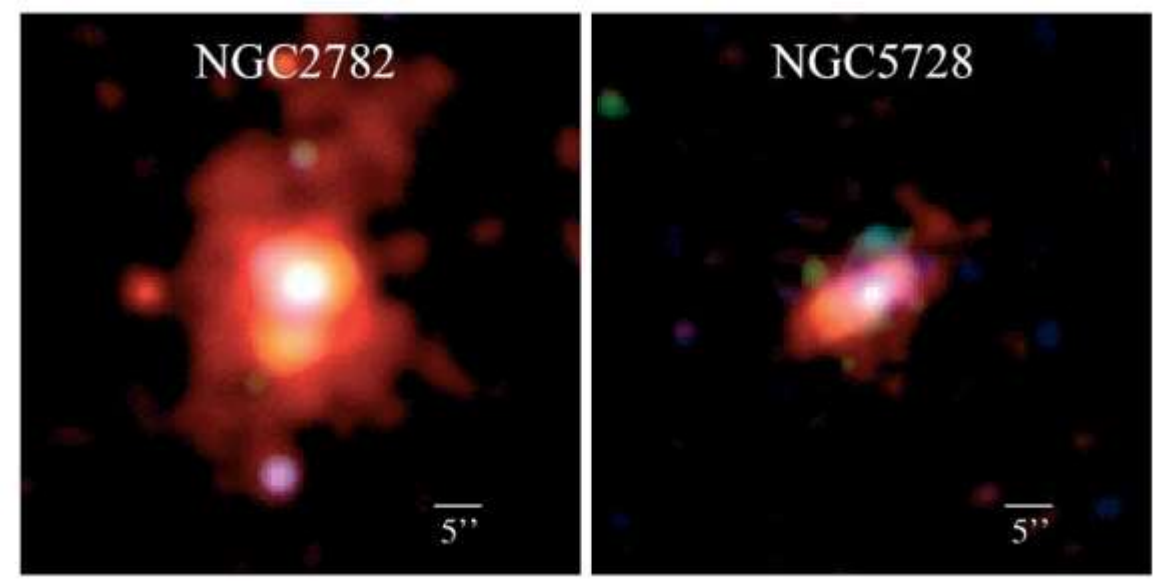
Correlation: X-ray and class I methanol emission

Explanation: X-ray heating; galactic outflow-driven shock excitation

Hint: methanol megamasers trace larger-scale feedback (e.g. outflows) and star formation in circumnuclear starburst regions of active galaxies.

36.2 GHz class I methanol megamaser survey with GBT

- Sample: 16 OH or water megamaser galaxies with extended soft X ray emission



- Aim:

  1) find more methanol megamaser sources

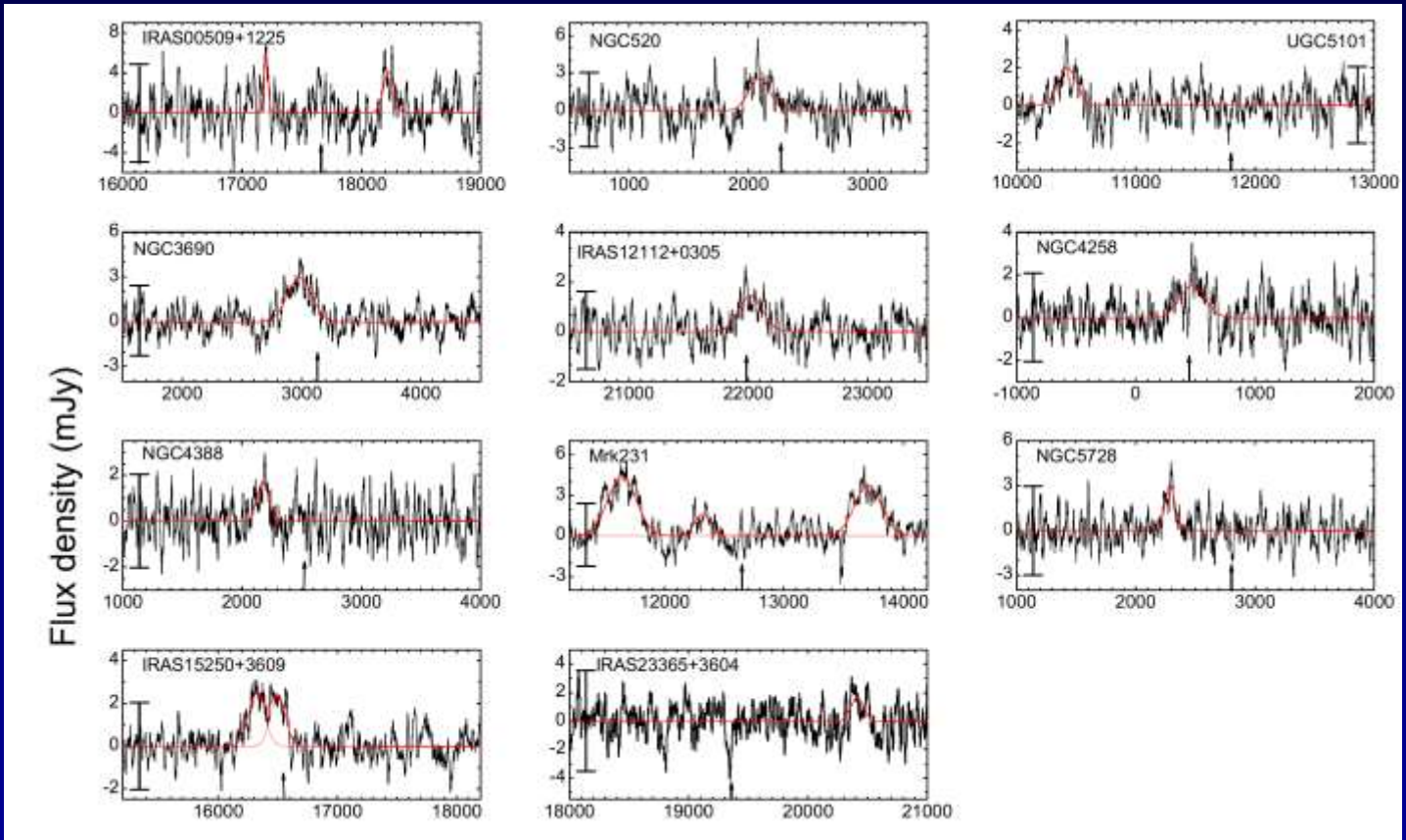
  2) pumping conditions?

  3) role of megamasers for studies of starburst and feedback processes of host galaxies.

36.2 GHz class I methanol megamaser survey with GBT

- Results:

Chen, X. et al. 2016 MNRAS



11 marginal detections in 15 targeted sources above 3 sigma
(1 sigma~ 1 mJy @ 20 km/s spectral resolution).

Flux density: 2-6 mJy
Linewidth: 40-200 km/s
Luminosity: 1-3000 Lsun
$>10^6$ times Galactic maser

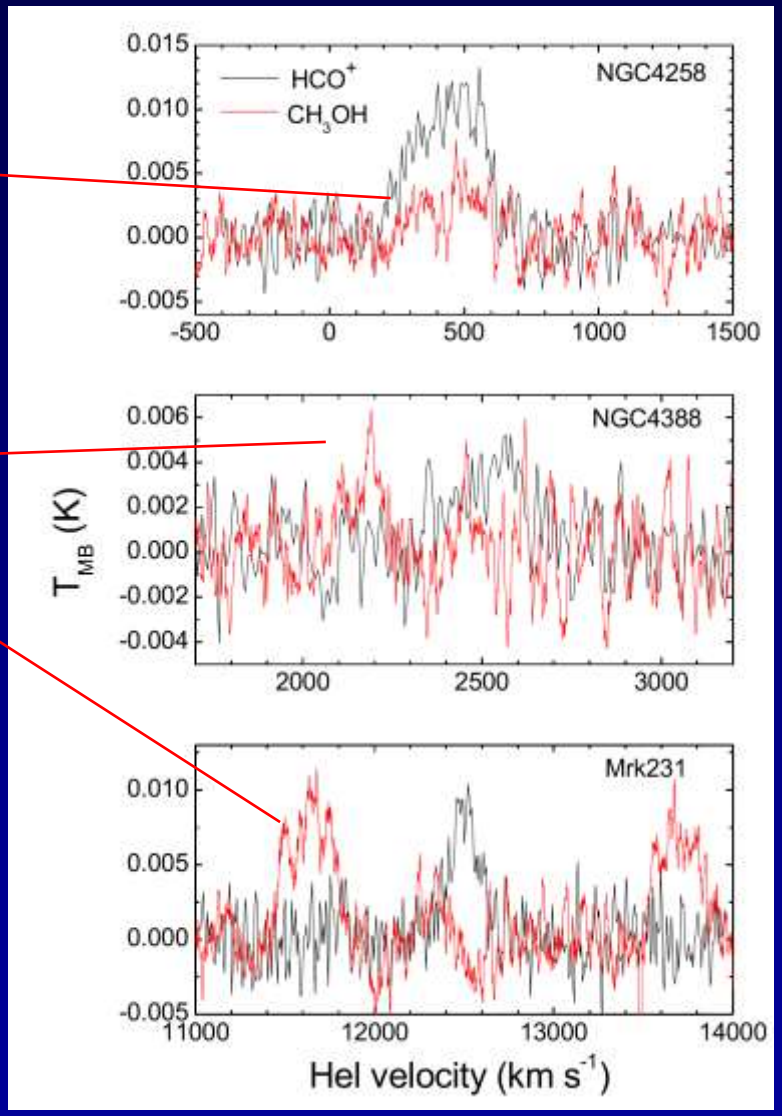
36.2 GHz class I methanol megamaser survey with GBT

- Emission feature characteristics:

Some features are well consistent with the systemic velocity and denser gas tracer HCO^+

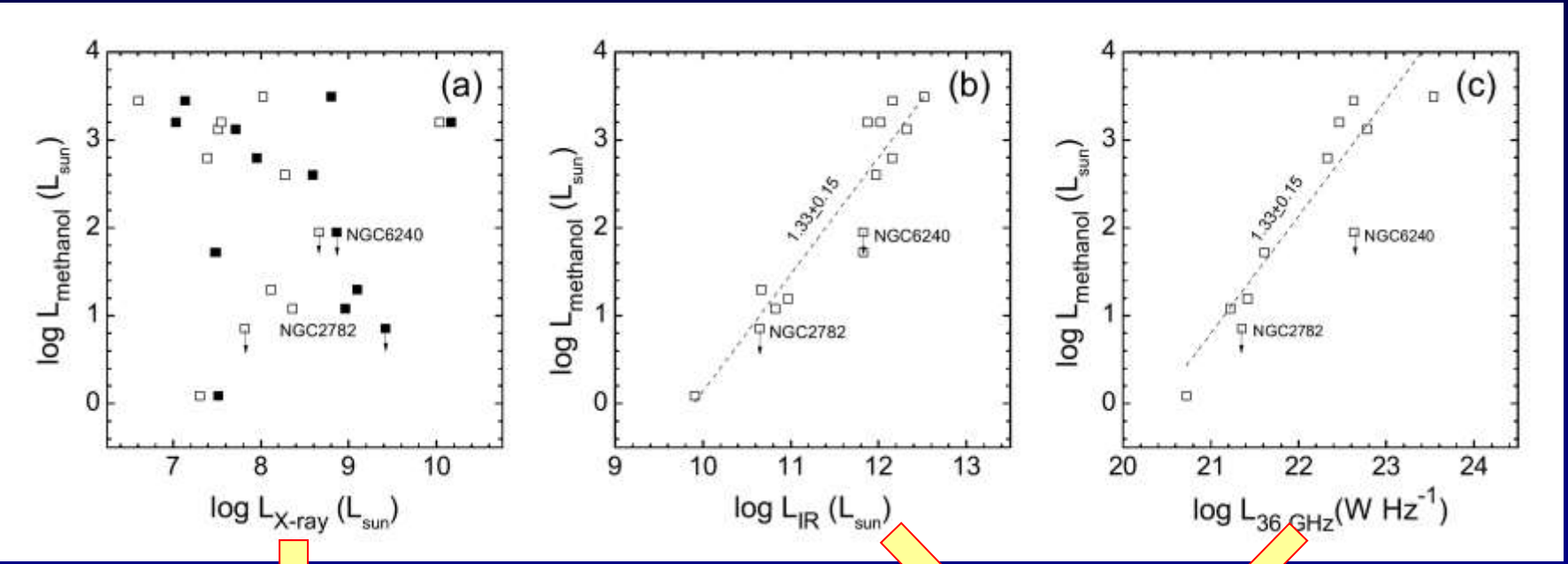
High-velocity methanol features (a few 100-1000 km/s)

Trace the galactic-outflow driven by the winds from the AGN feedback



36.2 GHz class I methanol megamaser survey with GBT

- Relationships among methanol emission and other band emission:



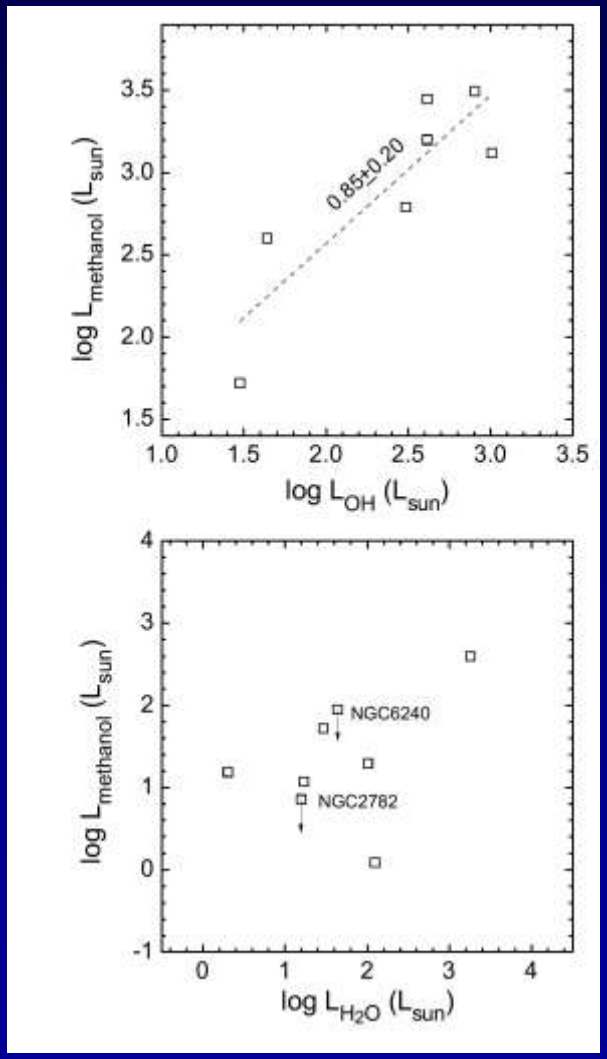
No correlation with X-ray

Good correlation with IR and Radio emission:
$L_{methanol} \sim L_{IR} \sim L_{36GHz}$

So, the 36.2 GHz methanol is not related to the X-ray emission of the galaxies, but are related to the starburst activities.

36.2 GHz class I methanol megamaser survey with GBT

- Relationships among methanol and OH and H_2O megamaser emission:



OH megamasers trace the starbust activities

good correlation with OH

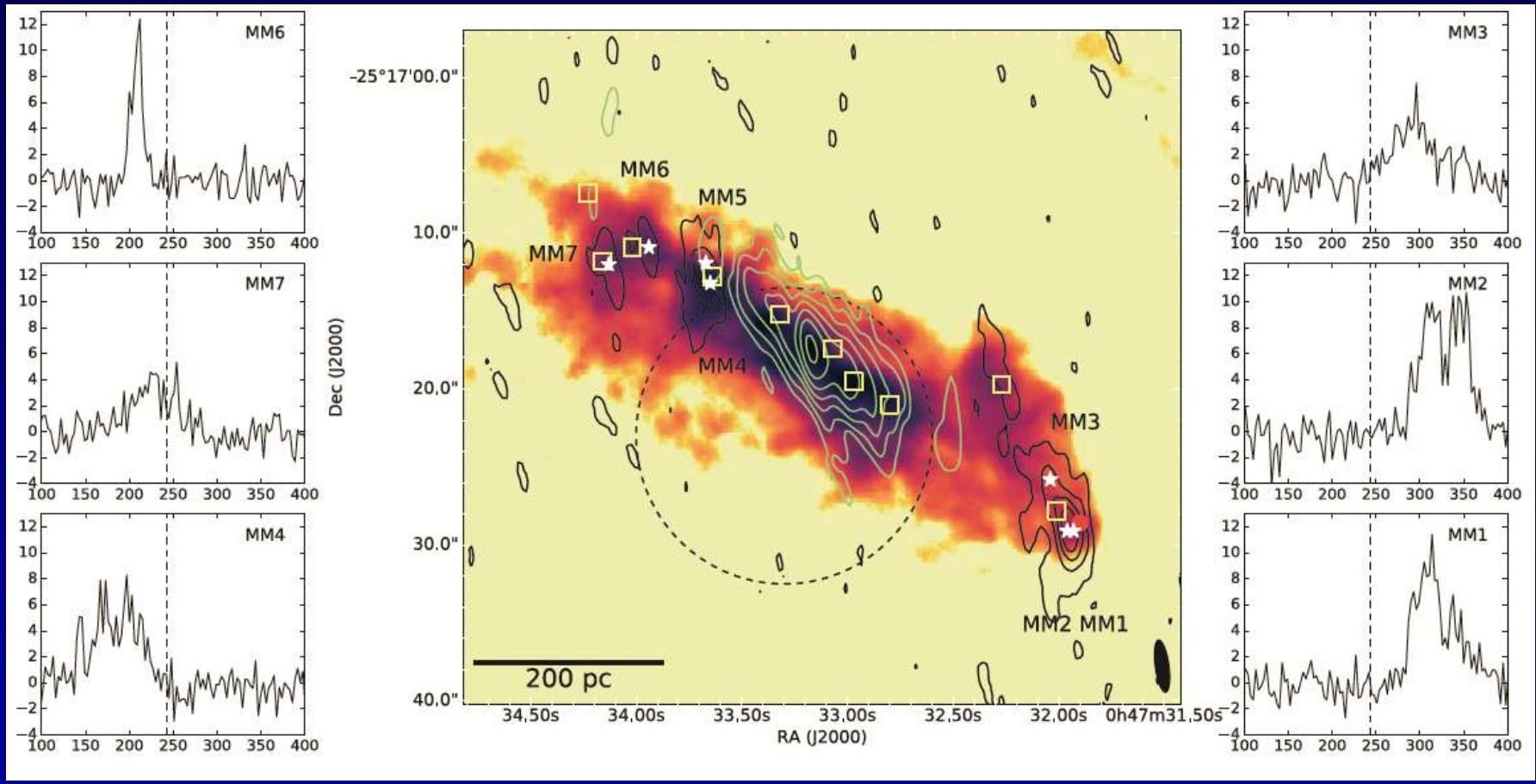
H_2O megamasers trace the disk and jests of AGNs.

no correlation with H_2O

This also suggests that the production of the methanol megamasers are related to the starburst activities, but not to the center region of the galaxy.

Follow-up higher-resolution observation with ATCA and JVLA

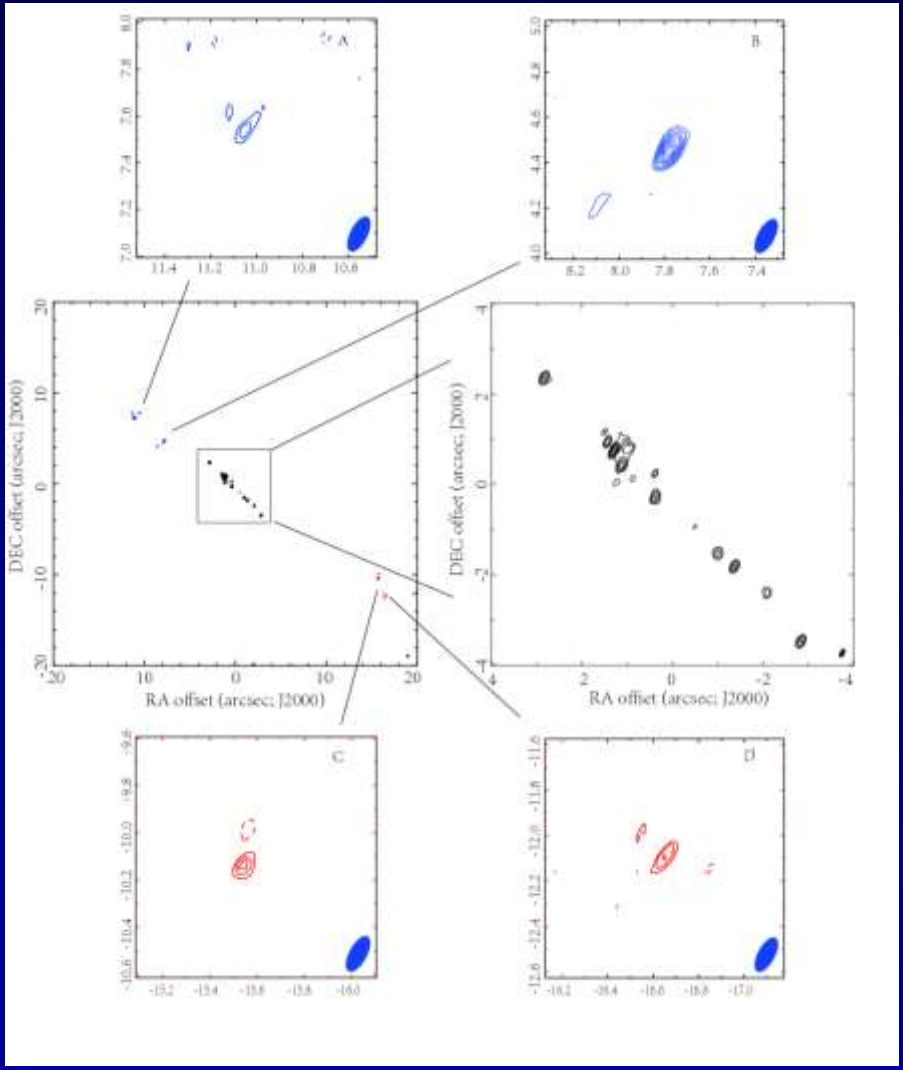
NGC253 Methanol: combined H168, EW367 and 1.5 A array data (resolution~3.3x0.9 arcsec)



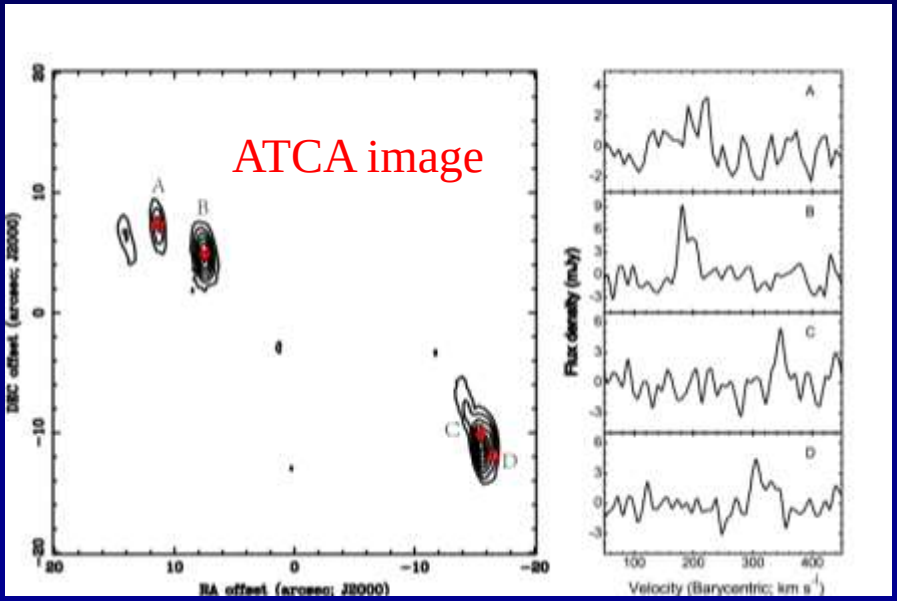
Ellingsen S. P., Chen X., et al. (2017, MNRAS, Accepted; See Ellingsen's talk)

Follow-up higher-resolution observation with ATCA and JVLA

NGC 253: JVLA at A-array (resolution ~0.1 arcsec)



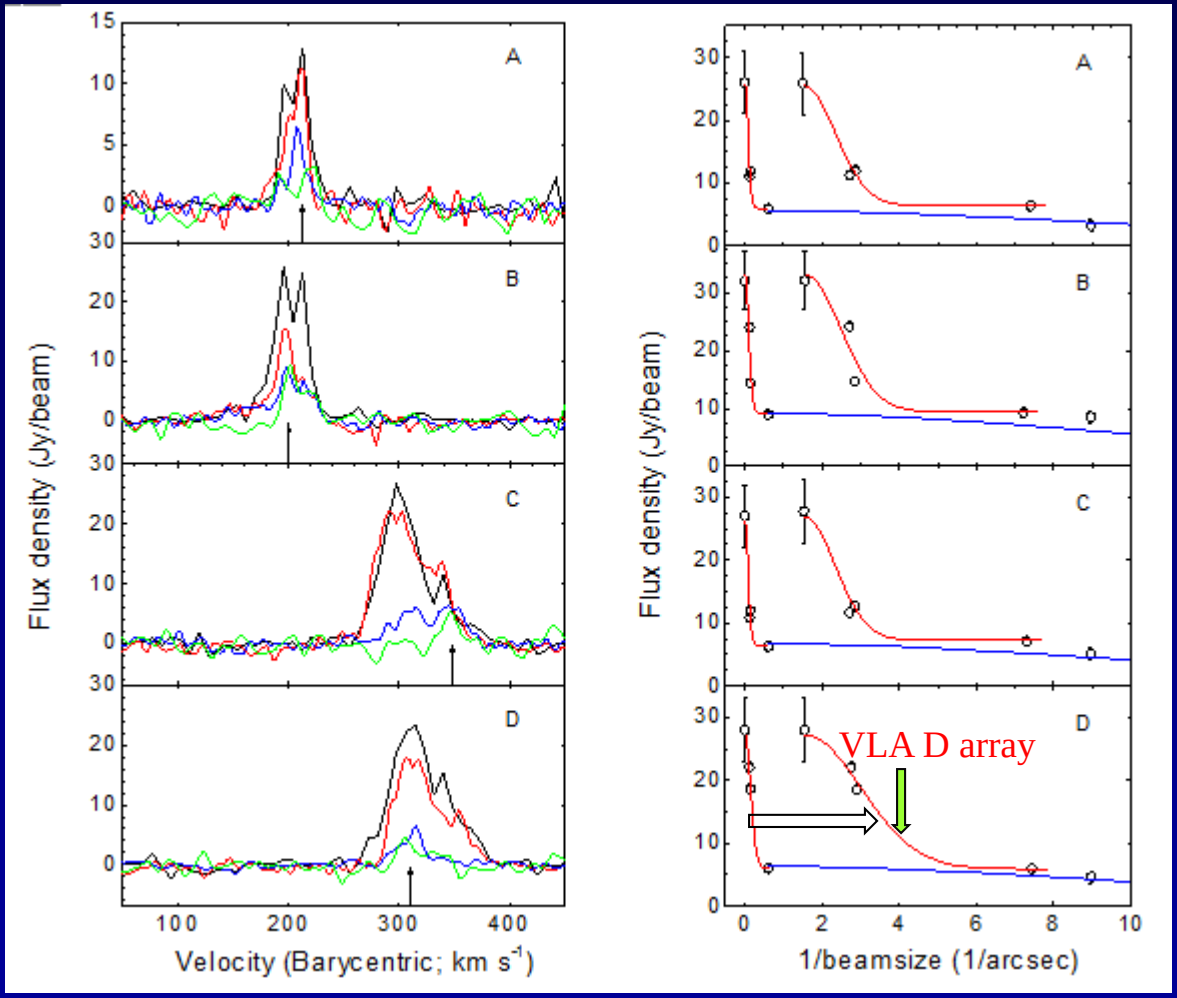
Chen et al. (in prep.)



- Brightness temperature: 2000-6000 K
- A direct evidence for maser emission from methanol.

Follow-up higher-resolution observation with ATCA and JVLA

NGC253: Scale of 36 GHz class I methanol maser



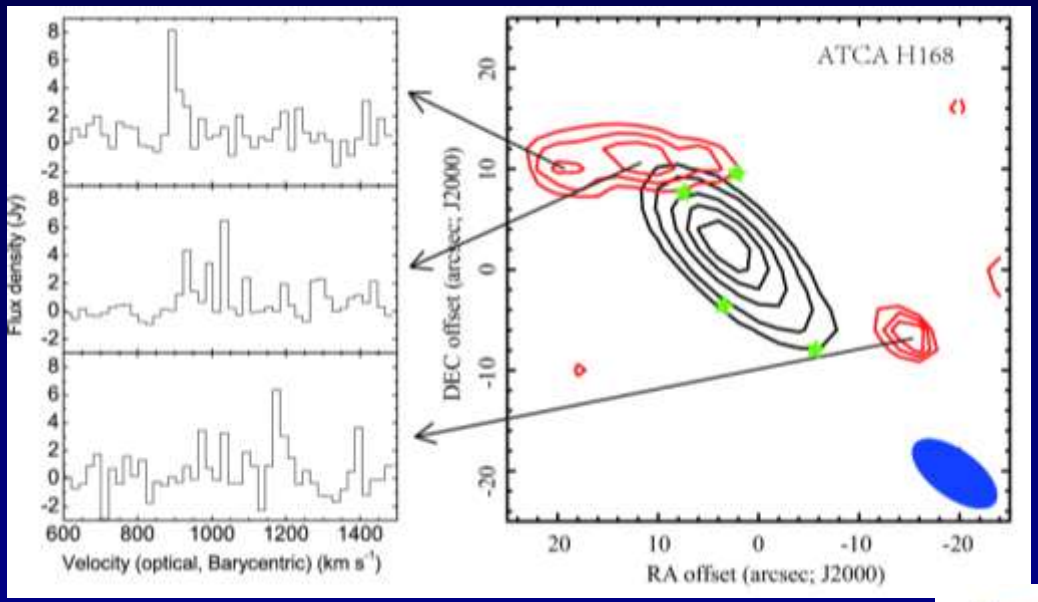
Extended+compact:

- Scale of extended component: ~ 6 arcsec
- Scale of compact component: ~ 60 mas

- **Implication:** JVLA at D array observation (~3 arcsec) will also resolve most (70%) of the extended methanol emission.

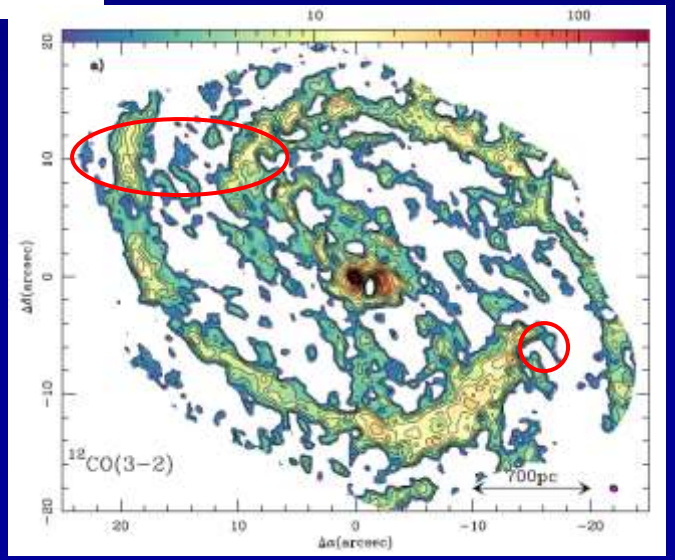
Follow-up higher-resolution observation with ATCA and JVLA

NGC1068: ATCA observation at H168 array (~9x6 arcsec)



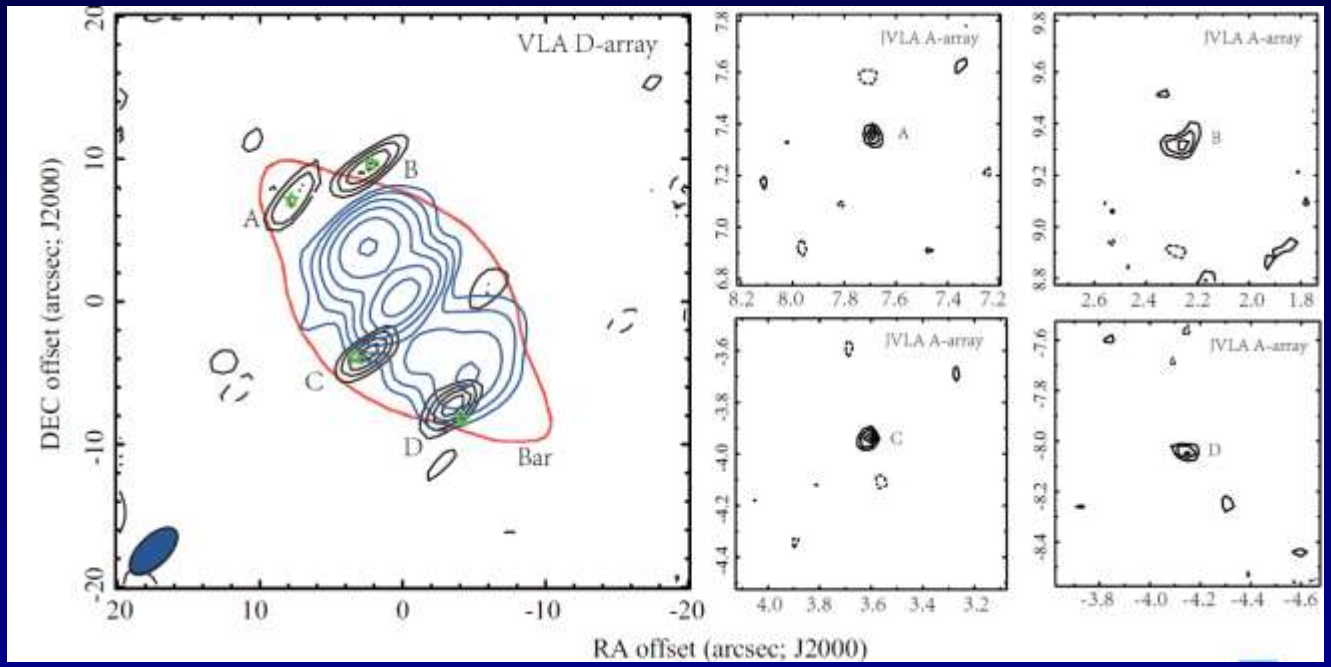
Chen et al. (in prep.)

- The extended methanol emission locate well in the starburst ring traced by the CO emission.



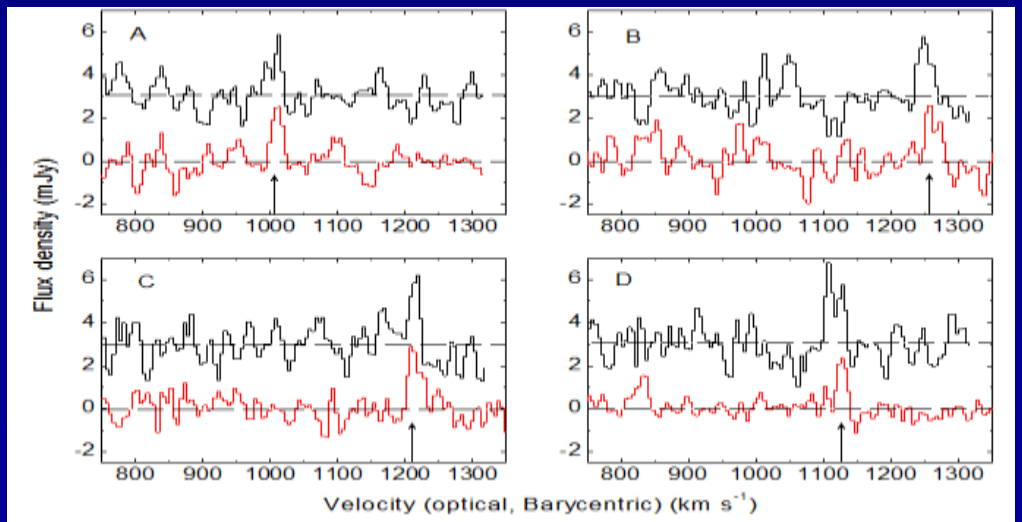
Follow-up higher-resolution observation with ATCA and JVLA

NGC1068: JVLA observations at D and A arrays



- **The compact emission locate the edge of the galactic bar !!**

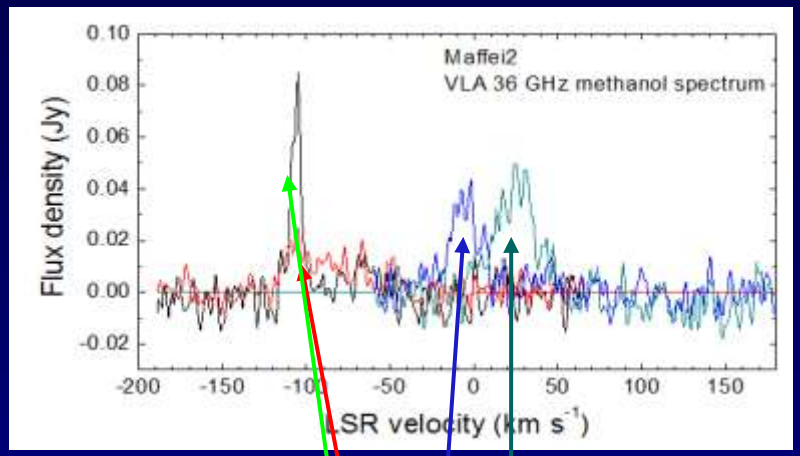
- **Shock between the bar and inflow /outflow gas excite the maser emission.**

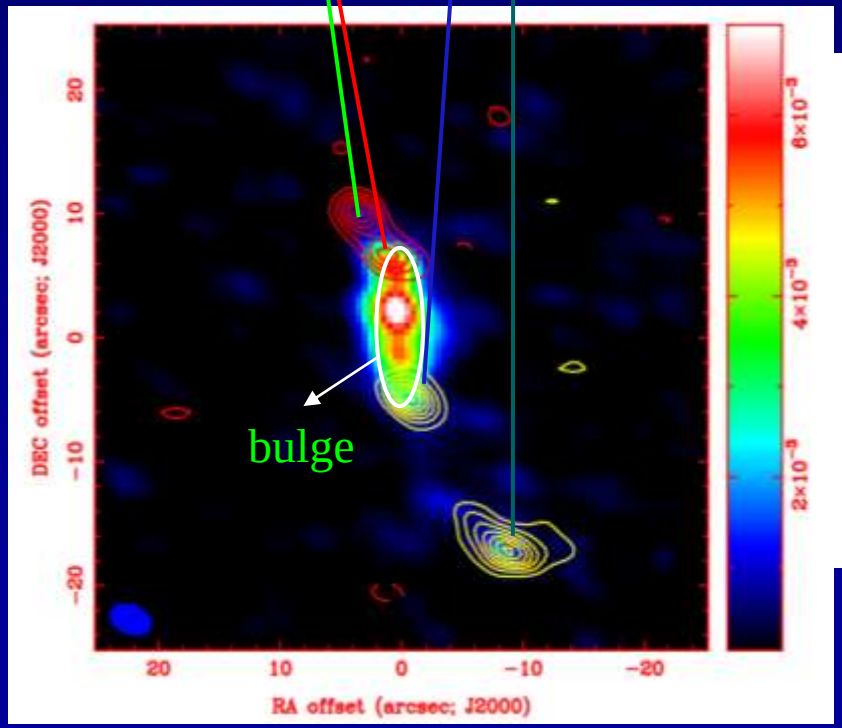


- Flux density is similar at A and D array observations, suggesting that the compact components are unresolved at both the two arrays.
- The brightness temperature is estimated to be >2000 k.

Other detections of extragalactic class I methanol masers

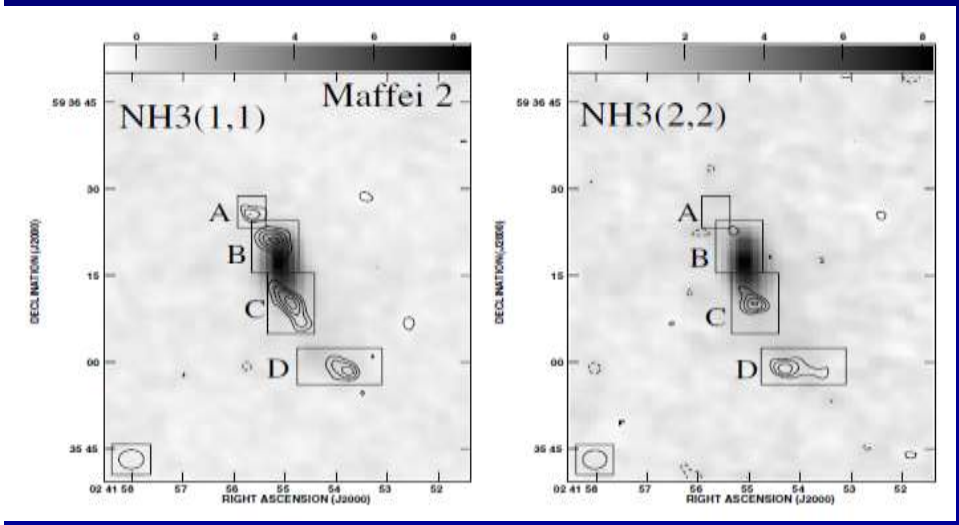
Maffei2: JVLA at D array observations





Chen et al. (in prep.)

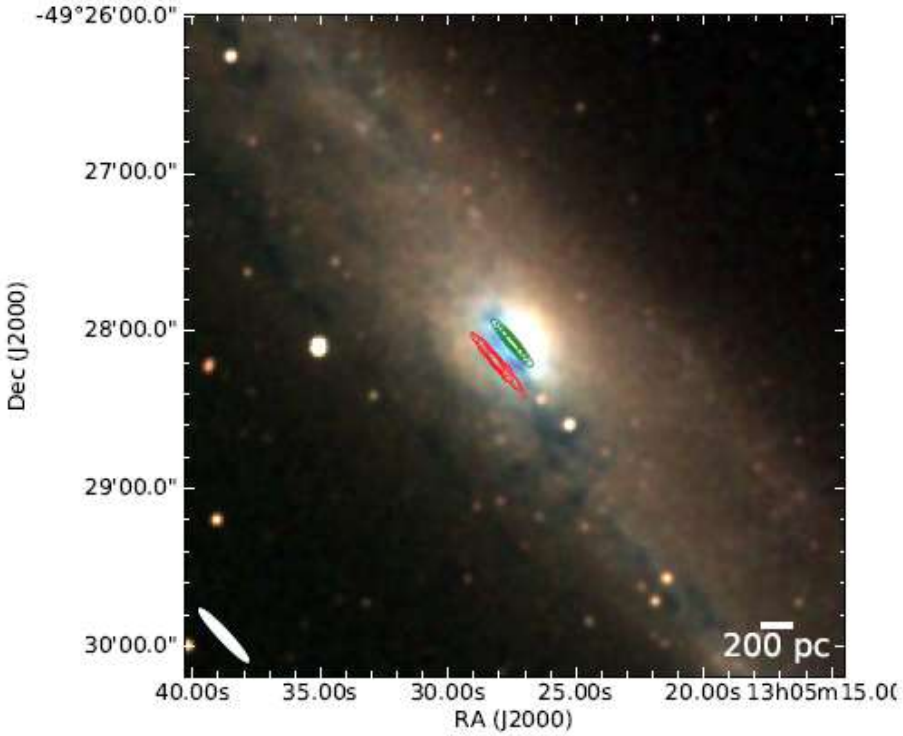
Methanol emission is well consistent with the hot NH_3 ➡ shocks in the star forming region along the galactic bar.

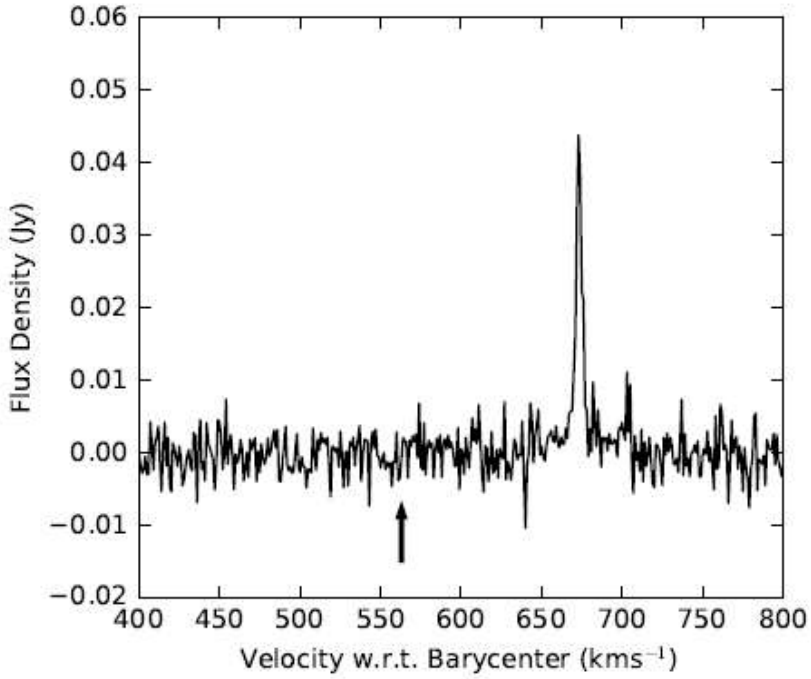


Other detections of extragalactic class I methanol masers

NGC4945: ATCA detections

McCarthy T. P., Ellingsen S. P., Chen X., et al. (ApJL, accepted; See McCarthy's talk)





- The maser emission may be associated with molecular inflow, which is observed in HF absorption

Summary for the current research

- **Extragalactic Class I methanol masers have been searches towards a few ten galaxies with ATCA, GBT and JVLA**
  - **The first survey with ATCA had mad significant detections towards NGC253 and Arp220, and they may be associated with starburst and excited by x-ray heating or jet/outflow driven shocks.**
  - **Marginal detections were made towards 11 out of 16 galaxies with GBT**
    - **Good correlations between methanol and IR, raidio, OH maser emission, suggesting the methanol maser production is related to starburst of the galaxies.**
    - **High-velocity methanol features (a few 100 to 1000 km/s) have been detected in some sources. They may associate with the galactic-outflow driven by the winds from the AGN feedback.**
  - **The higher resolution follow-up observations have made for two galaxies NGC253 and NGC1068 with JVLA at D and A arrays**
    - **The methanol emission consists of both the extended (~ 6 arcsecs) and compact (~60 mas) components.**
    - **The compact component located in the galactic bar edge, wherein the shock gas trigged by inflow or outflow gas .**
- **Pumping mechanism is still unclear:**
  - **Shocked gas trigged in the starburst region, bar edge, AGN wind-driven outflow, inflow …**

Class I methanol megamasers provide a new tool for investigating the starburst and feedback processes of active galaxies!

Thank You!